POLLEN MORPHOLOGY AS A TAXONOMIC TOOL IN LINUM[1]

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Among modern palynologists, Wodehouse (1935) and Erdtman (1952) most successfully show the use of pollen characters in taxonomy. The latter brings the knowledge of pollen morphology in 98 families of angiosperms, including the *Linaceae* more or less up to date. He classifies and describes the pollen of about 36 species, representing 14 genera of the family, including, however, only five species of *Linum,* all of which are of the Old World.

Small (1907) has provided the most thorough taxonomic treatment of the genus in North America, recognizing 60-70 species *(Linum* and *Cathartolinum),* but the relationships of these to one another and to species in other parts of the world have never been too clearly known. It was hoped that knowledge of the comparative morphology of the pollen might provide additional information and, for that reason, preliminary studies were undertaken, of which the present paper gives some results. Since these are sufficiently encouraging, a more extensive survey of the genus is now under way.

Fourteen species and six varieties of *Linum* were examined, principally eastern North American taxa, but including certain selected western North American and cultivated species.

Some of the pollen grains were collected from living plants, but most have come from herbarium specimens, since such grains are not only intact and perfectly usable, but scarcely differ from those taken from living plants of the same species.

The pollen was prepared according to Brandt's method as described in Wodehouse (1935) except that, in order to view the surface sculpturing better, most of it was left unstained. The grains were removed from the anther, placed on a slide,

[1]Contribution No. 96 from the Department of Biology, Wayne State University.

cleared in 95% alcohol and embedded in pure glycerin jelly. At ordinary temperatures, these slides are permanent. The shape as well as the external features of the pollen may be easily observed when the grains are floated in 95% alcohol in a deep well slide.

Two significant facts became quickly apparent. One, the pollen grains within most species show comparatively little variation, even when the plants have come from widely separated localities. Two, there is a rather remarkable amount of diversity among the different species.

Because of their variation and the clearness with which they can be seen, the pollen characters found to be most helpful in differentiating species are the size and shape of the grain, number, size and shape of the germ pores or furrows, the thickness of the exine and the nature of its sculpturing. Diameter of the grain varies from 38.5-112 μ. Shape ranges from triangular to subspherical. Triangular grains have three meridionally extended germ furrows which may be acute or blunt at the ends and vary in width and length in different species. Spherical grains have about 20 more or less circular pores while intermediate types have the surface undulated due to the protruded germ pores which are six to twelve in number and oblong in shape. Thickness of the exine ranges from 2-9 μ. The sculpturing of the exine consists of verrucoid (wartlike) excrescences, which may be mono-, di- or polymorphic and range from 0.5-5.25 μ in diameter. They may be rounded or many sided as viewed from above and be rounded or irregularly truncate at the summit. The excrescences vary in abundance and on the furrow membrane they may be absent, few, or as dense as on the other sporoderm surfaces.

Though some species are more clearly distinct than others, it is possible to construct a key based on pollen characters alone, by which most of the species studied may be identified. The sizes given in the key and in the descriptions which follow were obtained by making three to five series of measurements of each specimen. In using the key, one must take care to choose only polar views of fully expanded, unbroken grains.

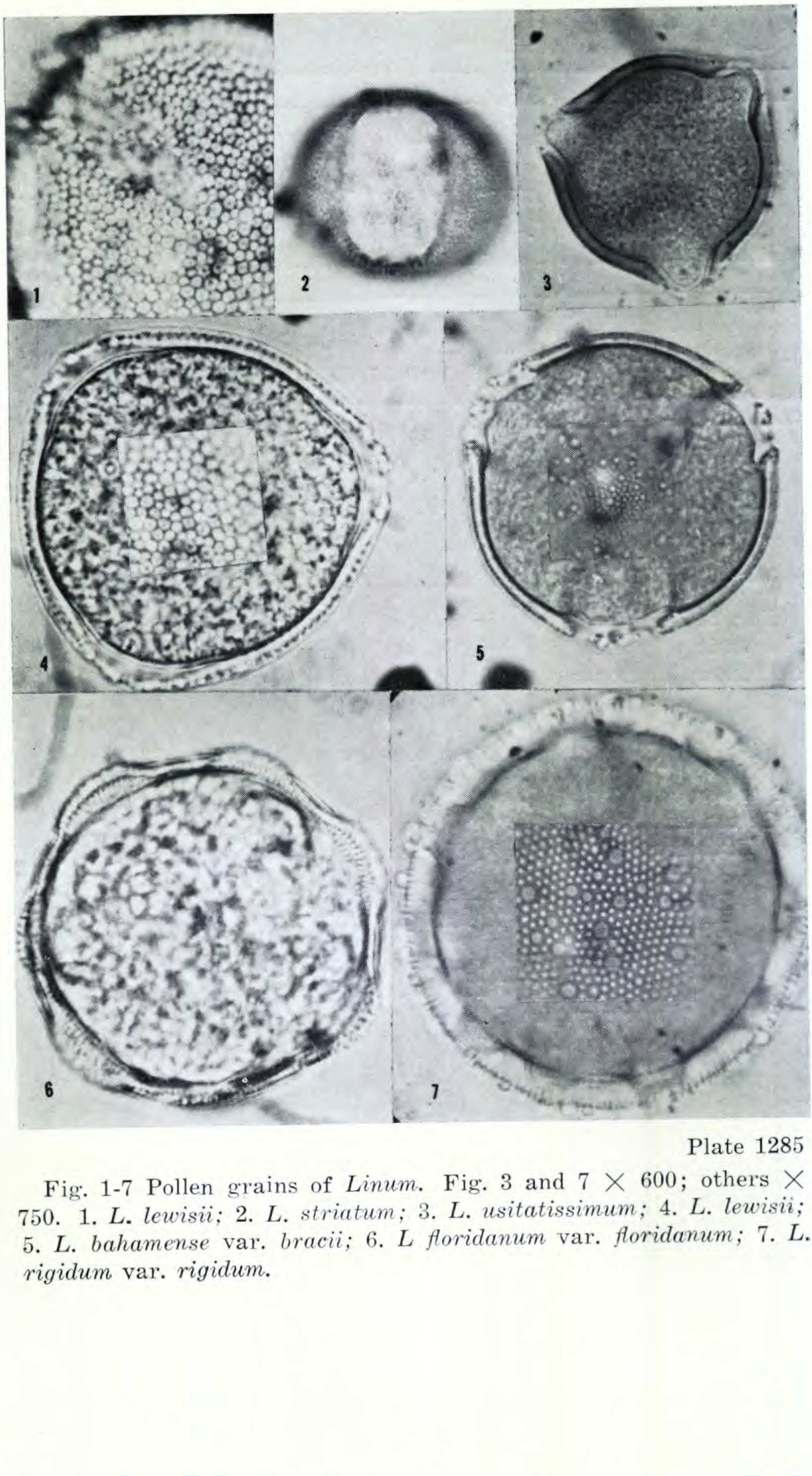

Plate 1285

Fig. 1-7 Pollen grains of *Linum*. Fig. 3 and 7 × 600; others × 750. 1. *L. lewisii;* 2. *L. striatum;* 3. *L. usitatissimum;* 4. *L. lewisii;* 5. *L. bahamense* var. *bracii;* 6. *L floridanum* var. *floridanum;* 7. *L. rigidum* var. *rigidum.*

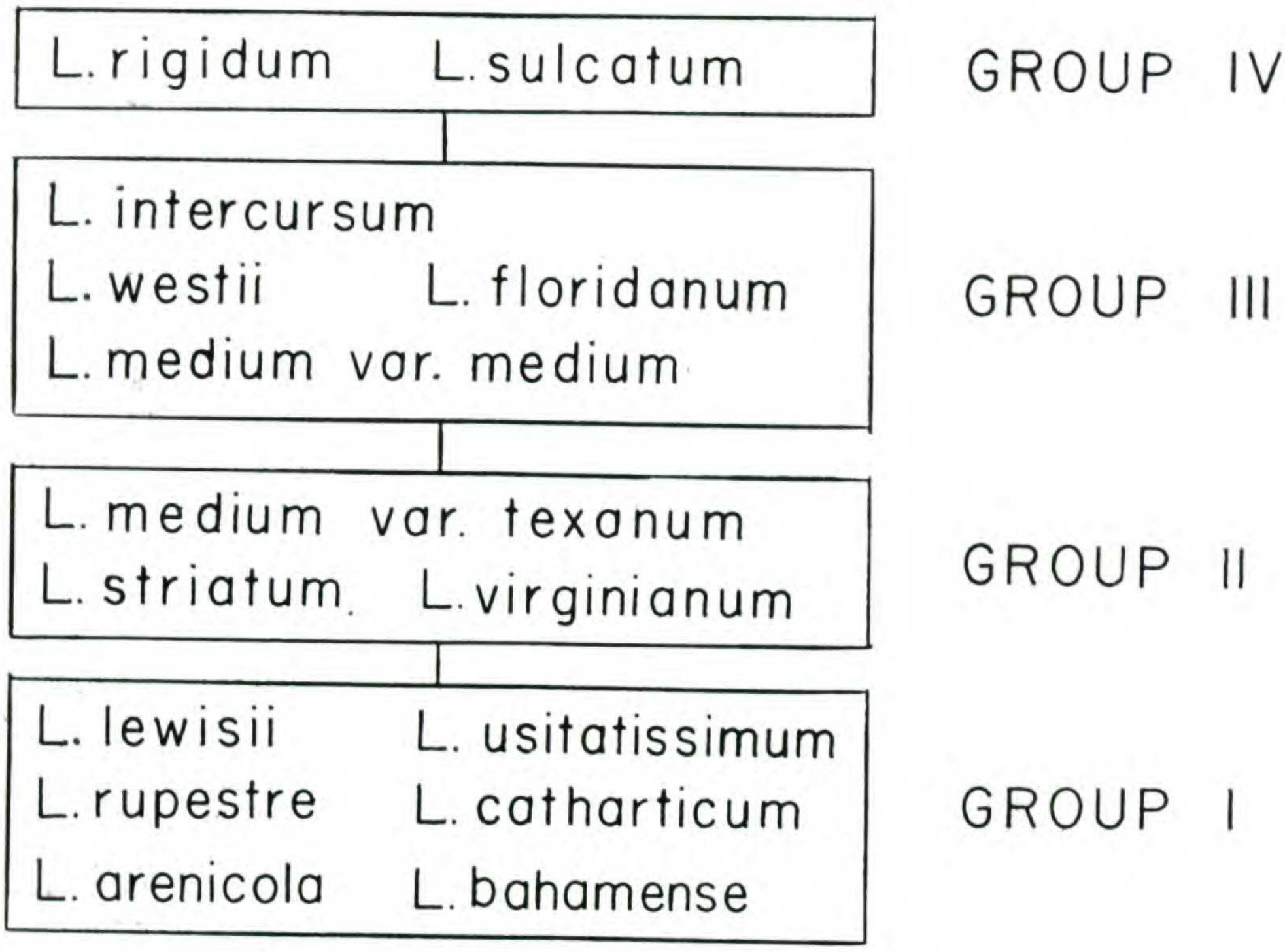

Fig. 8. The species of *Linum* studied, arranged in four groups on the basis of pollen morphology, with Group I being most primitive and Group IV most advanced.

KEY TO THE SPECIES

Germ furrows three.
  Germ furrows pointed at the ends (Group I) (Fig. 1).
    Excrescences 0.75-3 μ in diameter; intine broadly rounded at the furrows (Fig. 4).
      Diameter of grains 38.5-45.5 μ. 1. *L. catharticum*
      Diameter of grains 52-73.5 μ.
        Germ furrows 27 μ wide. 2. *L. rupestre*
        Germ furrows 10.5-21 μ wide.
          Excrescences 0.5-2 μ in diameter, 84-90 per 10 μ^2 (Fig. 5).
            3. *L. arenicola* and
            4. *L. bahamense*
          Excrescences 1.5-3 μ in diameter, 28-30 per 10 μ^2 (Fig. 4).
            5. *L. lewisii*
    Excrescences 0.5-0.75 μ in diameter; intine subacute at the furrows (Fig. 3). 6. *L. usitatissimum*
  Germ furrows rounded at the ends (Group II) (Fig. 2).
    Exine 2 μ thick; excrescences 70-72 per 10 μ^2.
      7. *L. striatum*

Exine 2.75-3.5 μ thick; excrescences 40-53 per 10 μ^2.
8. *L. virginianum* and
9. *L. medium* var. *texanum*

Germ pores six to twenty.
Germ pores six to twelve; surface of grain undulated (Group III) (Fig. 6).
Germ pores six.
Germ pores tapering toward the ends, 14 μ wide; excrescences in a central patch on the pore membrane.
10. *L. westii*
Germ pores subcircular, 21 μ in diameter; excrescences uniformly sparse on the pore membrane.
Excrescences with central pits, 40-44 per 10 μ^2.
9. *L. medium* var. *medium*
Excrescences without central pits, 67-75 per 10 μ^2.
11. *L. floridanum* var. *chrysocarpum*
Germ pores ten to twelve.
11. *L. floridanum* var. *floridanum* and
12. *L. intercursum*
Germ pores about twenty; surface of grain not undulated (Group IV) (Fig. 7).
Exine 5.25-7.5 μ thick.
Grains 70-87.5 μ in diameter; largest excrescences 3 μ in diameter.
13. *L. sulcatum*
Grains 84-112 μ in diameter; largest excrescences 5.25 μ in diameter.
14. *L. rigidum* var. *rigidum*
Exine 8.75-9 μ thick.
14. *L. rigidum* var. *carteri*

DESCRIPTIONS OF THE SPECIES

1. *L. catharticum* L. Compressed triangular, diam 38.5-45.5 μ; colpi 3, very long, narrow, pointed, 7-10.5 μ wide; exine 3.5-4.75 μ thick; excrescences monomorphic, diam 1.75 μ, many sided, sparse, absent on furrow membrane.

2. *L. rupestre* Engelm. Compressed, subtriangular, diam 70-73.5 μ; colpi 3, pointed, 27 μ wide; exine 3 μ thick; excrescences polymorphic, diam 0.75-2.5 μ, rounded, with central pits, very sparse on furrow membrane.

3. *L. arenicola* Small. Oblate triangular, diam 56-66.5 μ; colpi 3, long and pointed, 17.5-21 μ wide; exine 3 μ thick; excrescences polymorphic, diam 1-2 μ, rounded, with minute central pits, very sparse on the slightly bulging germinal furrows.

4. *L. bahamense* Northrop, including var. *bracii* (Small) Rogers and var. *corallicola* (Small) Rogers. Oblate triangular, diam 52.5-66.5 μ; colpi 3, long and pointed, 10.5-21 μ wide; exine 2.25-3 μ thick; excrescences rounded, di- or polymorphic, diam 0.5-1.5 μ, very sparse on the furrow membrane.

5. *L. lewisii* Pursh. Oblate triangular, diam 63-73.5 μ; colpi 3, 21 μ wide, pointed; exine 3-4.5 μ thick; excrescences di- or polymorphic, diam 1.5-3 μ, rounded or many sided with central pits, very sparse on furrow membrane.

6. *L. usitatissimum* L. More or less oblate triangular, diam 52.5-59.5 μ; colpi 3, short, pointed, 7-10.5 μ wide; exine 3.5-4.25 μ thick; excrescences dimorphic, diam 0.5-0.75 μ, absent on furrow membrane.

7. *L. striatum* Walt. Oblate triangular with blunt angles, diam 42-49 μ; colpi 3, oblong, 14-24.5 μ wide; exine 2 μ thick; excrescences monomorphic, diam 1.5 μ, many sided, with central pits, fewer on the furrow membrane.

8. *L. virginianum* L. Oblate triangular with blunt angles, diam 45.5-59.5 μ; colpi 3 (one specimen with 4), elliptic, 21-28 μ wide; exine 2.75 μ thick; excrescences monomorphic, diam 1.5 μ, many sided, with central pits, sparse on furrow membrane.

9. *L. medium* (Planch.) Brit. var. *medium*. Oblate triangular but tending toward spheroidal, diam 52.5-70 μ; pori 6, elliptic, 21 μ wide; exine 3-3.75 μ thick; excrescences monomorphic, diam 1.5-1.75 μ, many sided, with central pits, sparse on pore membrane.

L. medium var. *texanum* (Planch.) Fern. Compressed triangular, diam 42-56 μ; colpi 3, elliptic, 28-32 μ wide; exine 3.25 μ thick, excrescences monomorphic, diam 1.5-2.5 μ, fewer on the furrow membrane.

10. *L. westii* Rogers. Spheroidal with undulate surface, diam 63-66.5 μ; pori 6, oblong, with slightly tapering but blunt ends, 14 μ wide; exine 3 μ thick; excrescences monomorphic, diam 1 μ, rounded, without central pits, arranged on the furrow membrane as a central longitudinal patch.

11. *L. floridanum* (Planch.) Trel. var. *floridanum*. Spheroidal with undulate surface, diam 50.5-59.5 μ; pori about 10, small, rounded, diam 12-14 μ; exine 3.5 μ thick; excrescences monomorphic, diam 1.25 μ, rounded, without central pits, somewhat fewer on the bulging pore membrane.

L. floridanum var. *chrysocarpum* Rogers. More or less similar, sometimes appearing four-sided, diam 52.5-63 μ; pori usually 6, diam 21 μ; excrescences monomorphic, diam 1.75 μ, many sided, sometimes with central pits, fewer on the pore membrane.

12. *L. intercursum* Bickn. Spheroidal with undulate surface, diam 52.5-66.5 μ; pori about 12, rounded, diam 17.5 μ; exine 2.25 μ thick; excrescences monomorphic, diam 1.75 μ, many sided, somewhat fewer on furrow membrane.

13. *L. sulcatum* Ridd. including var. *harperi* (Small) Rogers. Subspheroidal, diam 70-87.5 μ; pori about 20, circular, diam 10.5-14 μ; exine 5.25-7.5 μ thick; excrescences polymorphic, diam 1.5-3 μ, cylindrical with rounded summit, nearly as dense on the pore membrane.

14. *L. rigidum* Pursh var. *rigidum*. Subspheroidal, diam 84-112 μ; pori about 20, circular, diam 10.5-12.5 μ; exine 5.25-7 μ thick; excres-

cences polymorphic, diam 1.5-5.25 μ, cylindrical, rounded at the summit, equally abundant on the pore membrane.

L. rigidum var. *carteri* (Small) Rogers. Similar, diam 91-108.5 μ; exine 8.75-9 μ thick.

It is generally thought that pollen grains with many circular pori and with excrescences on the pore membrane are more specialized than those with few, slender, pointed furrows with naked membranes. Correlated with these advanced traits in *Linum* are large excrescences and thick exine. Certainly additional species should be examined before definite conclusions can be drawn, but on the basis of those thus far studied, the pollen features thought to be primitive or advanced can be shown as follows:

PRIMITIVE FEATURES	ADVANCED FEATURES
Germinal furrows three	Germinal pores about twenty
Grain triangular	Grain spherical
Furrows slender, with pointed ends	Pores circular
Furrow membrane naked	Pore membrane with excrescences
Excrescences small	Excrescences large
Exine thin	Exine thick

Upon taking these characteristics into consideration, it is possible to segregate the species studied into four groups, the members of each group resembling one another in their important features. These groups are shown in Fig. 8.

It is not to be implied that the species studied or the groups shown constitute a single line of evolution, for information from pollen morphology alone is too scanty and data from all other sources possible must contribute to our knowledge. However, the species in Group I combine the greatest array of primitive features, those of Group IV, the largest number of advanced features, while Groups II and III are intermediate.

On the basis of observations on the general morphology of the various species, it would appear that Group I is a heterogeneous one in which, though evolution has proceeded in other directions, the pollen has remained rather unspecialized. *Linum arenicola*, *L. bahamense* and *L. rupestre* have very similar pollen. That of *L. lewisii* and *L. usitatissi-*

mum is rather different and the relationship of these species to each other and to the other species in the group is not clarified here.

Groups II and III, from their gross morphology, would be judged to be quite closely related to one another. The pollen morphology of the wide ranging species, *L. medium* var. *texanum*, *L. striatum* and *L. virginianum*, is very similar, as is that of *L. floridanum* and *L. intercursum*. *Linum westii*, *L. floridanum* var. *chrysocarpum* and *L. medium* var. *medium* appear to be intermediate between members of Groups II and III. The present studies indicate that the systematic position of the varieties of *L. medium* needs clarification.

The species of Group IV possess pollen that is significantly different from that of the other groups and the relationship of members of this group to those of the others needs further study.

Conclusions from other data (Rogers, 1963) that some members of Group I are most primitive and that Groups II and III and Group IV may be natural assemblages of successively more highly evolved species is given considerable support by the results of the study of pollen morphology.

Many workers in palynology have found it almost impossible to separate species within a genus and sometimes even different genera within a family on the basis of pollen morphology alone. In the species of *Linum* studied, generally speaking, though the pollen characters within a species are without much variation, one can distinguish many species rather readily. The large amount of variation, involving several characters, especially since it appears to be correlated with differences in gross morphology, may indicate that the usual treatment of *Linum* as a single genus is too conservative. The examination of other species, both Old and New World, may provide further information as to the proper systematic treatment of the genus. In any case there is little question but that the use of pollen characters will constitute a valuable additional tool in the study of the taxonomy of the genus.

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